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(54) [Title of the Invention]

PROJECTION ALIGNER

(57) [Abstract]

[Object] To allow for correction of distortion of a projection optical system by a relatively simple arrangement.

[Means for Resolution] An optical element L3, constituting a projection optical system PL for projecting a pattern formed on a reticle R onto a wafer W, is provided with temperature changing means, such as heaters H1 and H2. The optical element L3 is allowed to have a predetermined temperature distribution, resulting in physical deformation (L3'). Thus, the optical characteristics of the projection optical system PL are modified to correct distortion.

[Claims]

[Claim 1]

A projection aligner including an illumination system that illuminates a reticle, a substrate stage that holds a photosensitive substrate, and a projection optical system that forms an image of a pattern on the reticle on the photosensitive substrate, comprising: temperature changing means for changing the temperature of an optical element constituting the projection optical system; temperature measuring means for measuring the temperature distribution of the optical element; and temperature distribution control means for controlling the temperature changing means on the basis of the temperature distribution measured by the temperature measuring means so that the optical element has a predetermined temperature distribution to correct distortion of the projection optical system.

[Claim 2]

The projection aligner according to claim 1, wherein the temperature changing means includes a plurality of heat pumps arranged on the periphery of one or each of a plurality of optical elements constituting the projection optical system.

[Claim 3]

The projection aligner according to claim 1 or 2, wherein the temperature changing means includes infrared irradiation means for irradiating the optical element with infrared rays having a desired pattern and the temperature measuring means includes a radiation thermometer.

[Claim 4]

The projection aligner according to claim 1, further comprising: memory means for storing the temperature distribution of the optical element in association with the optical characteristics of the projection optical system.

[Claim 5]

The projection aligner according to claim 1, further comprising: simulation means for simulating the imaging characteristics of the projection optical system as a result of control over the temperature changing means by the temperature distribution control means, wherein the temperature distribution control means controls the temperature changing means on the basis of simulation by the simulation means.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to a projection aligner used for making a semiconductor device, a liquid crystal display, or the like.

[0002]

[Prior Art]

In a photolithography process of making a semiconductor device, a liquid crystal display, a thin film magnetic head, or the like a projection aligner projects a pattern formed on a photomask or a reticle (hereinafter, the reticle) onto a photosensitive substrate, such as a wafer or a glass plate, applied with a sensitizer, e.g., a photoresist and exposes the substrate. In general pattern exposure, a step of superimposing a pattern on another pattern already formed on a photosensitive substrate and exposing the substrate is repeated multiple times. Since the overlay accuracy of patterns formed on the photosensitive substrate directly affects the performance of a device, serving as a completed product, a projection optical system of the projection aligner requires minimizing deformation (distortion) of an image. In addition to minimizing distortion which is caused in principle upon designing a projection lens, it is therefore necessary to minimize a manufacturing error and an assembly tolerance of an optical element caused during manufacture. Furthermore, since distortion of the projection optical system varies due to a change in environmental parameters, such as atmospheric pressure and temperature, and a change in the temperature of the optical element caused when the optical element absorbs exposure light during exposure, it is necessary to compensate for the variation.

[0003]

The following approaches to suppressing the error and tolerance caused during manufacture of the projection aligner have been performed: One approach is to reduce an error of an optical element to be used. For example, efforts have been made to make a refractive optical element (so-called optical lens) having characteristics close to ideal characteristics in optical design. An optical material having a high uniformity of refractive index is used and the material is worked with a very high precision so that the optical element has ideal characteristics in optical design. Another approach is to devise a mount so that the accurate positional relationship between the mount and a completed optical part is held without deforming the completed optical part, thus achieving the designed performance.

[0004]

However, manufacturing the projection optical system of the projection aligner requires very high performance. In some cases, the manufacturing accuracy required for individual parts may exceed the limit of processing accuracy obtained using current techniques. Accordingly, the necessary performance cannot be obtained by only the above-described methods. In fact, parts of a completely assembled projection optical system are repeatedly adjusted to achieve the necessary performance of the projection optical system through a trial and error process.

[0005]

As for the variation in distortion caused by a change in operating environment, according to one approach, the whole of the projection optical system is disposed in an environmental control system, alternatively, the projection optical system is covered with a temperature control jacket to protect the optical system from a change in external environment. According to another approach, the projection optical system is partially sealed so that the pressure in sealed part is controlled. According to another approach, a part of optical elements is moved to compensate for a variation in distortion caused by environmental changes.

[0006]

[Problems that the Invention is to Solve]

The above-described known projection aligner has the following problems: An error caused during manufacture is compensated for by adjusting the completely assembled projection optical system, serving as a completed product. It requires high accuracy for adjustment. In addition, not all of performances of the assembled product can be adjusted.

[0007]

Regarding correction of distortion of the projection optical system, some of the distances between optical elements constituting the projection optical system are adjusted, so that most of rotationally symmetric components of the distortion can be corrected. Some of non-rotationally symmetric components can be corrected by three-dimensionally moving the optical elements. However, it is difficult to correct all of components after completion of manufacture of the product in terms of accuracy and accessibility.

[0008]

When an optical glass member constituting the optical element has a refractive index distribution or a support is deformed,

distortion cannot be corrected unless the optical system is disassembled into parts and a relevant part is replaced. It is therefore difficult to estimate the number of parts to be assembled into the aligner. It is also difficult to arrange a schedule for making the aligner. Unfortunately, it results in an increase in cost of the aligner. Adjustment in the case where an environmental parameter, such as temperature, in the use of the aligner changes and that for change over time have similar problems. The present invention is made in consideration of the above-described problems and an object of the present invention is to provide a mechanism capable of correcting various components of distortion with a flexible and relatively simple structure to a projection optical system mounted on a projection aligner.

[0009]

[Means for Solving the Problems]

According to the present invention, an optical element constituting a projection optical system is systematically allowed to have a temperature distribution and the optical element is physically deformed, thus correcting distortion.

[0010]

In other words, according to the present invention, a projection aligner having an illumination system (IU) that illuminates a reticle, a substrate stage (ST) that holds a photosensitive substrate (W), and a projection optical system (PL) that forms an image of a pattern on the reticle (R) on the photosensitive substrate includes temperature changing means (H1, H2, HP1 to HP8, SC) for changing the temperature of an optical element (L1 to L6) constituting the projection optical system (PL), temperature measuring means (S1 to S8, IR) for measuring the temperature distribution of the optical element, and temperature distribution control means (TC) for controlling the temperature changing means on the basis of the temperature distribution measured by the temperature measuring means so that the optical element has a predetermined temperature distribution to correct distortion of the projection optical system.

[0011]

Any of the following types of temperature changing means is available. A type of temperature changing means is in contact with the optical element and allows the optical element to have a temperature distribution by heat conduction. Another type of temperature changing means applies heat to the optical element in a contactless manner.

Both of the types may be used in combination. As for the contact type temperature changing means, heating means, such as a plurality of heaters (H1, H2), or heating and cooling means, such as heat pumps (HP1 to HP8), may be used such that the means is arranged on the periphery of one or each of a plurality of optical elements constituting the projection optical system. As for the contactless type temperature changing means, infrared irradiation means (SC) for irradiating the optical element with infrared rays having a desired pattern may be used.

[0012]

As the temperature measuring means, a plurality of temperature sensors (S1 to S8), e.g., thermocouples may be used such that the sensors are arranged in the vicinity of the optical element. When a radiation thermometer (IR) including an infrared imaging device or the like is used as the temperature measuring means, the temperature distribution of central part of the optical element can be measured in a contactless manner. The thermocouples for measuring the temperature distributions of peripheral parts of the optical element and the radiation thermometer for measuring the temperature distribution of central part thereof may be used in combination as the temperature measuring means. The temperature distribution control means (TC) controls the temperature changing means so that the temperature distribution of the optical element measured by the temperature measuring means indicates a desired temperature distribution. Thus, high precise control can be achieved.

[0013]

Since the contact type temperature changing means, e.g., the heaters or heat pumps are arranged on the periphery of the optical element, the means can be attached to an optical element disposed in any position, e.g., an optical lens located in a central portion of a body tube (T). The use of the heat pumps or the like having a cooling capability in combination with the heaters or the like having a heating capability enables the optical element to have a large temperature gradient. However, an attachment position is limited to the periphery of the optical element in order to widen the effective area of the optical element. Accordingly, heat cannot be directly conducted to a central area of the optical element close to the optical axis thereof. Disadvantageously, a temperature distribution pattern which the optical element can have is restricted.

[0014]

On the other hand, the contactless type temperature changing means, such as an infrared beam scanner, can apply heat directly to an area in the vicinity of the optical axis of the optical element without reducing the effective area of the optical element. Advantageously, the flexibility of a temperature distribution pattern which the optical element can have is relatively high. However, optical elements capable of being irradiated with an infrared beam are generally limited to those disposed in upper and lower ends of the projection optical system. In addition, the optical elements can be heated but cannot be cooled. As described above, the contact and contactless types of temperature changing means have functions that complement each other. The combination of both the types allows for higher precision correction of distortion of the projection optical system than that in the use of any of the types.

[0015]

To correct distortion of the projection optical system, first, a known pattern, e.g., a lattice pattern is projected onto an image plane through the projection optical system, deformation of the imaged pattern is measured to obtain the distortion of the projection optical system. Subsequently, in order to correct the obtained distortion, it is determined which of the optical elements of the projection optical system is allowed to have what temperature distribution. After that, in order to realize the temperature distribution, variables controlled by the temperature distribution control means, e.g., currents to be supplied to the respective heaters are obtained and the control operation by the temperature distribution control means is performed. Since it is difficult to analytically obtain the controlled variables, the variables are derived by linear operation or simulation based on actual measurement data.

[0016]

The principle of correction of distortion of a projection optical system according to the present invention will now be described with reference to Figs. 1 and 2. Fig. 1 schematically shows a refractive type projection optical system including optical lenses L1, L2, and L3. An image of a pattern on a reticle R uniformly irradiated with illumination light IL is formed on a wafer W applied with a sensitizer, e.g., a photoresist through a group of the optical lenses L1 to L3. Heaters H1 and H2 are attached to the periphery of the optical lens L3 as shown in the diagram.

[0017]

When the heaters H1 and H2 are not energized, the temperature of the optical lens L3 is uniform. Reference symbol I denotes an image point on the wafer W corresponding to an object point O in the pattern on the reticle R at that time. It is assumed that a lattice pattern P as shown in Fig. 2(a) is formed on the reticle R. When this pattern P is projected onto the wafer W through the projection optical system including the optical lenses L1 to L3, the formed image of the pattern P is distorted as shown in Fig. 2(b). At that time, the heater H1 attached to an upper portion of the optical lens L3 is energized to generate heat, thus allowing the optical lens L3 to have a temperature distribution. Heated part of the optical lens L3 is expanded, so that the optical lens L3 has a shape L3' shown by a broken line. Consequently, the image formed on the wafer W is deviated and an image point I' corresponds to the object point O, thus forming a distortion-free image on the wafer W as shown in Fig. 2(c).

[0018]

Simultaneously energizing the heaters H1 and H2 enables peripheral part of the optical lens L3 to be thicker than central part thereof. In this case, the optical lens L3 functions as a concave lens and can magnify an image. Alternatively, a heat pump, such as a Peltier element, may be used instead of a heater. The peripheral part of the optical lens is cooled lower than the central part thereof, allowing the peripheral part to be thinner than the central part. In this case, the optical lens L3 functions as a convex lens.

[0019]

The principle has been described using a very simplified example. In actuality, the optical lens L3 has a complicated temperature distribution caused by energization of the heater H1, therefore, the amount of deviation of an image formed on a relevant portion is complicated. Accordingly, it is necessary to analyze a variation in distortion caused by the temperature differences among various parts of the optical lens L3 by thermal analysis using the finite element method, optical simulation, or the like and to make a close study of arrangement of sensors for temperature measurement and heating means and cooling means for providing a temperature distribution. In addition, it is important to prevent thermal disturbance to the optical lens.

[0020]

When the present invention is applied to a refractive optical element, it is necessary to select the physical property of a material

for the optical element in accordance with the amount of correction of distortion. Available optical materials for the optical element of the projection aligner are limited due to a reduction in wavelength of exposure light of recent years. Fluorite ( $\text{CaF}_2$ ) has a relatively high coefficient of linear expansion and also has high transmittance to ultraviolet rays emitted from a KrF or ArF excimer laser or the like. Accordingly, fluorite is a suitable material for use in the projection optical system according to the present invention.

[0021]

According to the present invention, the temperature of an optical element is changed without moving the optical element to physically deform the optical element, thus correcting distortion of the projection optical system, which has been adjusted by changing relative positions of the optical elements. Advantageously, mechanical parts for adjustment needed so far can be omitted, resulting in simplification of the structure and reduction in the cost. Furthermore, not only changing the temperature of the optical element but also allowing the optical element to have a temperature distribution enable the optical element to be partially deformed. Advantageously, distortion which cannot be corrected by the known methods, for example, non-rotationally symmetric components or relatively random components of distortion can be corrected.

[0022]

[Mode for Carrying Out the Invention]

Embodiments of the present invention will be described below with reference to the drawings. Fig. 3 is a schematic view illustrating a projection aligner according to a first embodiment of the present invention. The projection aligner includes an illumination optical system IU, a reticle stage RS that holds a reticle R, a projection optical system PL, and a wafer stage ST that is two-dimensionally movable while carrying a wafer W. The whole of the aligner is received in an environmental control chamber EC such that air-conditioning control is performed to provide constant temperature. In this embodiment, the projection optical system PL comprises a refractive optical system including six optical lenses L1 to L6. A body tube T holding the optical lenses L1 to L6 is covered with a temperature control jacket TJ so that higher precision temperature control is performed.

[0023]

Illumination light IL emitted from the illumination optical

system IU is uniformly applied to the reticle R on which a projection pattern is drawn. The illumination light IL is subjected to intensity modulation and diffraction by the pattern drawn on the reticle R, so that the light containing information about the pattern is incident on the projection optical system PL. The projection optical system PL forms the image of the pattern drawn on the reticle R onto the wafer W.

[0024]

Regarding the optical lens L1 that is the uppermost one of the optical lenses constituting the projection optical system PL, heat pumps HP1 to HP8, such as Peltier elements, and temperature sensors S1 to S8 are attached to the periphery of the optical lens L1 as shown in Fig. 4 such that the combinations each including one heat pump and one temperature sensor are symmetrically arranged. A temperature controller TC controls the temperatures of the respective heat pumps HP1 to HP8 on the basis of temperature measurements obtained by the temperature sensors S1 to S8. The heat pumps HP1 to HP8 are individually heated or cooled so that the corresponding portions on the periphery of the optical lens have different temperatures, alternatively, the temperatures of the corresponding portions are made different from a temperature set in the environmental control chamber EC or the temperature control jacket TJ, thus allowing the optical lens L1 to have a temperature distribution.

[0025]

Changing the temperatures of the respective portions of the periphery of the optical lens through the heat pumps HP1 to HP8 enables the optical lens L1 to function as a concave lens or a convex lens, but also to function as an aspherical lens that is more complex. For example, in the optical lens L1, the temperatures of the portions corresponding to the heat pumps HP1 and HP5 located in opposite positions with respect to the optical axis are raised. On the contrary, the temperatures of the portions corresponding to the heat pumps HP3 and HP7, which are located at opposite positions with respect to the optical axis such that the arrangement of the heat pumps HP3 and HP7 is orthogonal to that of the heat pumps HP1 and HP5, are lowered. Consequently, non-rotationally symmetric distortion can be corrected. Changing a combination of temperatures allows for correction of distortion having a more complex shape.

[0026]

A memory device M, such as a ROM or a magnetic disk, is provided

for the temperature controller TC. The memory device M stores data indicating the relationship between the temperature distribution of the optical lens L1 and a variation in distortion of the projection optical system PL. The data can be obtained by actual measurement or simulation. Data obtained by actual measurement can be collected as follows: The optical lens L1 constituting the projection optical system PL is allowed to have a given temperature distribution, an image of a lattice pattern as shown in Fig. 2(a) on the reticle R is projected onto the image plane of the optical lens L1 having the temperature distribution, and the amount of deviation of the projected pattern from a design position is measured. A given temperature distribution is sequentially varied. The above-described process is repeated as the temperature distribution is varied. Data obtained by simulation can be collected by analyzing variations in distortion obtained at various temperature distributions of each optical element by thermal analysis using the finite element method, optical simulation, or the like.

[0027]

Controlled variables of the respective heat pumps HP1 to HP8 by the temperature controller TC can be determined by projecting the lattice pattern shown in Fig. 2(a) to measure distortion of the projection optical system PL and obtaining a temperature distribution necessary for correction of the distortion from data stored in the memory device M using linear operation. The temperature controller TC controls the heat pumps HP1 to HP8 using the controlled variables determined as described above while monitoring outputs of the temperature sensors S1 to S8, so that the distortion of the projection optical system PL is corrected.

[0028]

Fig. 5 is a schematic diagram showing a projection aligner according to a second embodiment of the present invention. The aligner according to the second embodiment shown in Fig. 5 includes an infrared beam scanner SC and a radiation thermometer IR, such as a two-dimensional CCD infrared imager, in addition to the components of the aligner according to the first embodiment in Fig. 3. Further, the aligner according to the second embodiment includes a simulation device SM instead of the memory device. In Fig. 5, components having the same functions as those in Fig. 3 are designated by the same reference numerals and a detailed description of the previously described components is omitted.

[0029]

The infrared beam scanner SC scans a surface of an optical lens L1 exposed in the upper end of a projection optical system PL at high speed while changing the intensity of an infrared beam, thus applying a desired heating pattern onto the optical lens L1. In other words, the optical lens L1 is simultaneously subjected to temperature control by heat pumps HP1 to HP8 arranged on the periphery of the optical lens as shown in Fig. 4 and temperature control by irradiation with the infrared beam. Although it is impossible for the heat pumps to heat an area in the vicinity of the optical axis of the optical lens L1, the infrared beam scanner SC can apply heat to this area, resulting in higher precision temperature control than temperature control using only the heat pumps HP1 to HP8. Preferably, a wavelength of infrared rays scanned by the infrared beam scanner SC is set to a wavelength at which an optical glass material constituting the optical lens L1 significantly absorbs infrared rays. Using the infrared rays having a wavelength for providing high absorption by the optical lens L1 allows for heat application to only the target optical lens L1 without affecting other optical lenses L2 to L6. Instead of the infrared beam scanner, illumination means for irradiating the optical lens L1 with a beam of infrared rays having a desired intensity pattern (for example, a circular pattern having such an intensity that central part has a high intensity and peripheral part has a low intensity) may be arranged in an illumination optical system IU. In this case, the same advantages as those in the use of the infrared beam scanner can be obtained.

[0030]

In the use of the radiation thermometer IR, the temperature distribution of the entire optical lens L1 including the central part thereof, which cannot be measured by temperature sensors S1 to S8 arranged on the periphery of the optical lens L1, can be measured.

[0031]

The simulation device SM may have a function of simulating the imaging characteristics of the projection optical system PL using, for example, the finite element method on the basis of the temperature distribution of the optical lens L1. As for correction of distortion of the projection optical system PL, a known pattern is projected to measure distortion of the projection optical system PL and the temperature distribution of the optical lens L1 necessary for correction of the measured distortion is obtained by means of the

simulation device SM. While monitoring the temperature distribution of the optical lens L1 measured by the radiation thermometer IR in real time, a temperature controller TC controls the heat pumps HP1 to HP8 arranged on the periphery of the optical lens L1 and the infrared beam scanner SC so that the temperature distribution agrees with that obtained by the simulation device SM. Consequently, the temperature controller TC modifies the optical characteristics of the projection optical system PL to correct the distortion.

[0032]

The simulation device SM may have a function of simulating the imaging characteristics of the projection optical system PL using, for example, the finite element method on the basis of control parameters supplied from the temperature controller TC, the control parameters including the amounts of current supplied to the heat pumps HP1 to HP8 arranged on the optical lens L1 and an infrared irradiation pattern of the infrared beam scanner SC, the pattern being applied to the optical lens L1. In this case, various control parameters are input to the simulation device SM. The simulation device SM simulates a change in distortion of the projection optical system PL. Consequently, the optimum control parameters can be found. The temperature controller TC may control temperature changing means in accordance with the optimum parameters.

[0033]

Alternatively, the simulation device SM may be automatically driven so as to automatically output the optimum control parameters for correction of distortion on the basis of input data regarding measured distortion of the projection optical system PL.

[0034]

As described above, the simulation device SM is mounted on the projection aligner, so that a temperature distribution pattern can be changed in real time. In the use of simulation results previously calculated using, for example, the finite element method, thermal calculation can be approximated by linear operation because of a small difference in temperatures actually applied to an optical material, such as fluorite, having a relatively high coefficient of linear expansion. Thus, highly flexible setting can be performed. This arrangement is not limited to fluorite but can also be applied to any optical material as long as a variable is very small or an error is acceptable.

[0035]

In the above description, the temperature changing means, such as heat pumps and an infrared scanner, is arranged on only the uppermost optical lens L1 of the optical elements constituting the projection optical system. Generally, it is advantageous to arrange the temperature changing means to an optical element that is close to an object or an image. In a demagnification projection optical system, it is advantageous to arrange the temperature changing means to an optical element close to an object. The position of an optical element provided with the temperature changing means is not limited to the upper end or the lower end of the projection optical system. The temperature changing means may be arranged on an optical element inside the body tube. Furthermore, the temperature changing means can be arranged on a plurality of optical elements.

[0036]

In the above description, the temperature changing means includes a heater, a heat pump, such as a Peltier element, and an infrared beam scanner. Furthermore, application of a warm or hot current of air from the end of a nozzle or microwave irradiation may be performed to control the temperature distribution of an optical element.

[0037]

[Advantage of the Invention]

According to the present invention, various components of distortion of a projection optical system mounted on a projection aligner can be corrected with a relatively simple arrangement.

[Brief Description of the Drawings]

[Fig. 1] Fig. 1 is a diagram explaining the principle of correction of distortion of a projection optical system according to the present invention.

[Fig. 2] Fig. 2 includes diagrams showing a pattern on a reticle and its images.

[Fig. 3] Fig. 3 is a schematic diagram showing a projection aligner according to an embodiment of the present invention.

[Fig. 4] Fig. 4 is a schematic diagram of an optical lens to which heat pumps and temperature sensors are attached.

[Fig. 5] Fig. 5 is a schematic diagram illustrating a projection aligner according to another embodiment of the present invention.

[Description of the Reference Numerals and Signs]

EC... environmental control chamber

H1, H2... heater

HP1 to HP8... heat pumps  
I... image point  
IL... illumination light  
IR... radiation thermometer  
IU... illumination optical system  
L1 to L6... optical lenses  
M... memory device  
O... object point  
PL... projection optical system  
R... reticle  
RS... reticle stage  
S1 to S8... temperature sensors  
SM... simulation device  
ST... wafer stage  
T... body tube  
TC... temperature controller  
TJ... temperature control jacket  
W... wafer